Conformal Ablative Thermal Protection System for Planetary and Human Exploration Missions:

An Overview of the Technology Maturation Effort

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IPPW-10
June 17-21, 2013
San Jose, Ca

Overview - 1

- **Current NASA ablative heatshield materials require either high part count or extreme touch labor**
- **NASA has made some progress in light weight ablators like the material flown on the recent Mars Science Laboratory, but that design required 123 tiles with complicated gap filler**
- **But as good as it is, NASA is getting smarter and knows it can make better material**
- **Better in what way?**
  - Material that isn't constrained to current manufacturing dimensions of 50x100 cm… but now can be made 150x100 cm or even larger – this significantly reduces part counts
  - Material that can deliver the same or better performance but with less weight where every pound saved can be added to more science
  - Material that is more compliant than the Mars Science Laboratory heatshield material (PICA) - this makes it more robust to loads and deflections and can save weight as well
  - Material that, because of it's compliance, can be directly bonded to an aeroshell and installed without gap filler

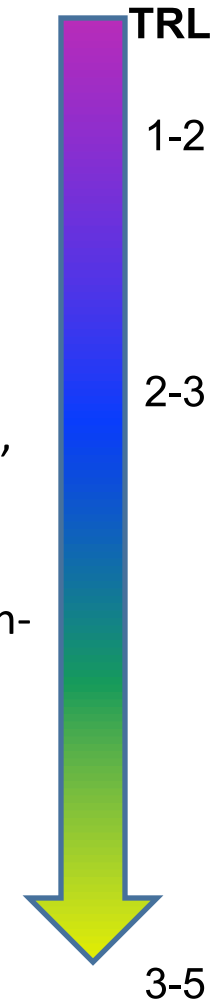
Overview - 2

- **The NASA Game Changing Division of the Space Technology Mission Directorate and precursor programs have supported the development of a new, carbon-based conformal high strain-to-failure thermal protection material by NASA Ames Research Center.**
- **Conformal ablator definition**
  - Based on a flexible reinforcement (felt)
    - Allows for large geometry segments (broad goods)
  - Drape-able or formable during processing for easy integration
    - Provides lower thermal conductivity in complex curved regions
  - Favorable/improved strain-to-failure over PICA
    - Eliminates need for strain isolation pads (direct bond to substrate)
    - Simplifies gore-to-gore geometries and allows gore-to-gore bonding (gap fillers eliminated)

ARC Recent History of Conformal and Flexible Ablative Materials Development

Conformal Ablators

- **2007-2011 Funded by ARMD Fundamental Hypersonics to develop improvements to PICA in toughness**
  - Initial research into baseline conformal PICA based on carbon felt with phenolic impregnation
- **2009-2011 Funded by ESMD Entry Descent and Landing Technology Development Project (EDL TDP) to develop flexible TPS**
  - Developmental versions of several families of materials based on carbon, organic, and silica felts impregnated or mixed with phenolic or silicone resins
  - Results showed silica-based materials very capable q<130 W/cm^2, carbon-based materials capable to at least 500 W/cm^2
- **NOW: 2+ year project funded by Space Technology Mission Directorate Game Changing Division (STMD GCDP) to develop conformal ablators with the capability of at least 250 W/cm^2 and MSL-level shear**



Conformal Ablator Capability Drivers

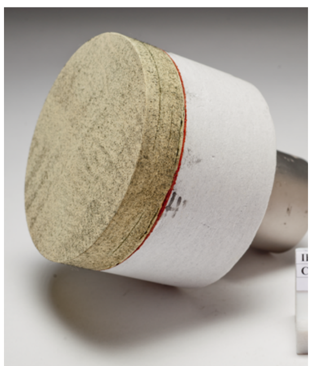
Key Performance Parameters (KPP's)

Conformal Ablators Key Performance Parameters	Category *Definition*	State-of-the-Art Value	Justification
KPP-C1	**Survivable for MSL-like and COTS aerothermal environments** *Capability required for future Mars and COTS missions*	PICA: >250 W/cm^2, 0.33 atm, 490 Pa shear	Current goal for Conformal Ablator is to meet MSL-like conditions while satisfying COTS heat shield conditions
KPP-C2	**Strain to Failure > 1%** *Material property that provides an indication of compliance when bonded to an underlying structure*	PICA (<<1%) Avcoat (~1%)	High strain to failure and use of felts for substrates enables factor of >10 reduction in heat shield parts count
KPP-C3	**Manufacturing Scalability** *Assesses the likelihood that the technology concept will successfully scale to the large sizes required by mission architectures*	20" x 40" PICA max tile size (1m cast monolithic)	Eventual application will require large panels, seams, and close-outs. Heat loads define ablator thickness. The MDU, arcjet testing, and analysis will prove scalability of the ablator to full scale.
KPP-C4	**Response Model Fidelity** *Ability to reliably and repeatably predict the thermal response of the material to the applied environments*	Mean: bias error 30%, Time to peak error: 30% Recession: 150%	Working from low to mid to high fidelity models - need the ability to estimate thicknesses for target mission design

Screening Arc Jet Testing Approach

- Test many material variations in stagnation conditions to determine best 2 materials

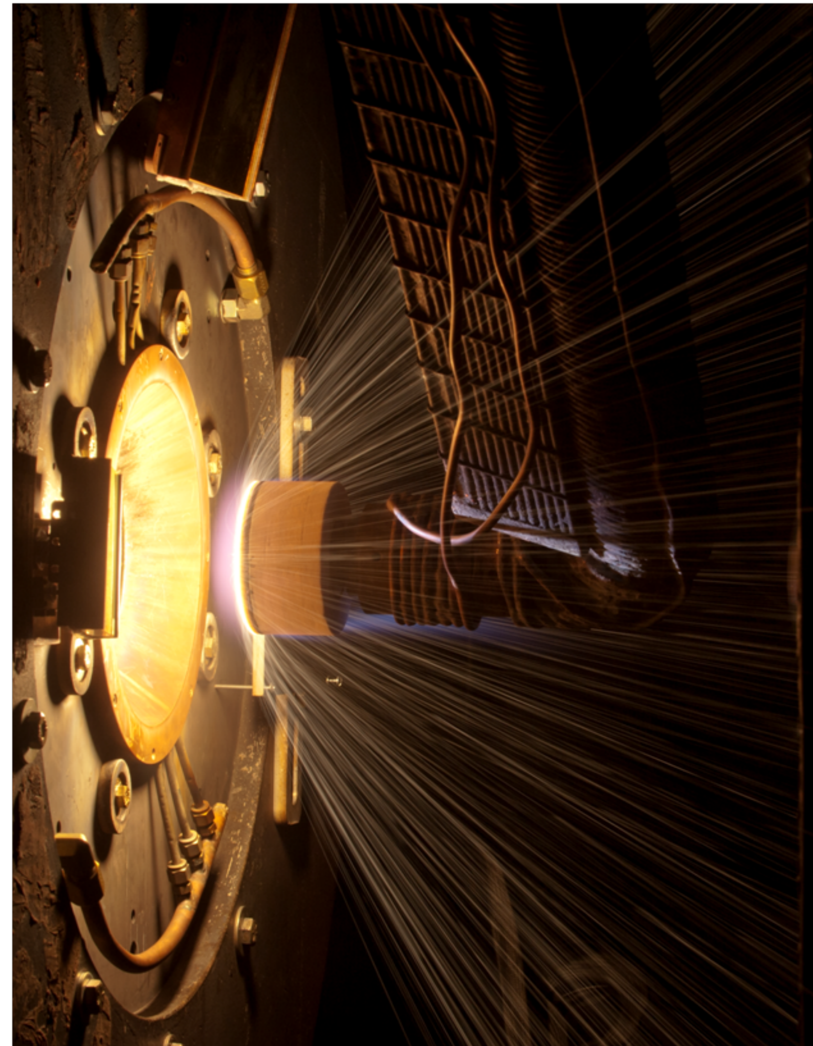
Pre test



Post test

Pre test

Post test

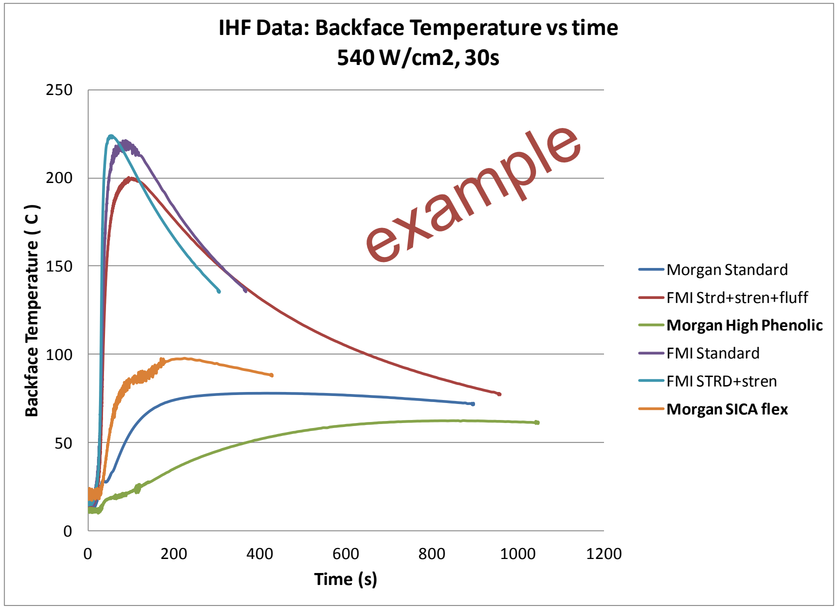


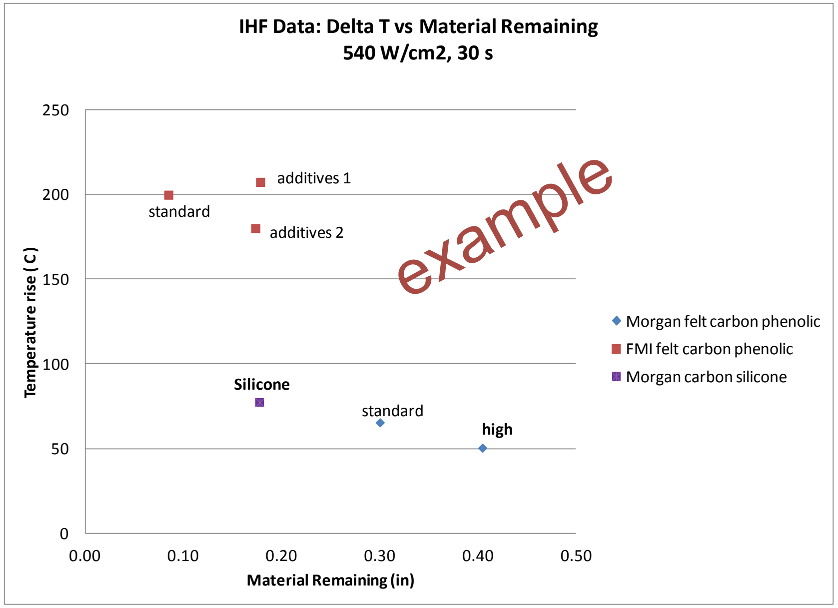
Screening Test Data

- **ARMD 2010-2011 data on conformal standard**
  - IHF arc jet stagnation and wedge data
  - Limited strain-to-failure (meets requirement)
- **EDL TDP 2011 data on flexible ablators – 20 materials tested**
  - JSC arc jet stagnation data
  - HyMETS arc jet stagnation data
  - Strain-to-failure (all meet requirement)
- **CA250 data on conformal ablators – 7 material variations**
  - Started with ARMD conformal "recipe" as baseline
  - Varied felt type, resin loadings and additives
  - Plus included flexible PICA and Carbon felt/silicone variants
  - IHF arc jet stagnation data
  - Limited strain-to-failure

Data Evaluation Approach

- **Data evaluations performed for each test series to compare:**
  - Recession vs Density
  - Backface temperature increase vs Areal Density
  - Backface temperature increase vs Remaining Thickness
  - Backface temperature vs Time
- **Strain-to-failure measurements**





FY12 Screening Down-Select Evaluation Matrix

- **Quantitative criteria scoring categories based on KPP's included**
  - Ablative Performance (30%): Survivability, Shape Stability, Recession Rate
  - Thermal Performance (25%)
  - Strain-to-Failure (25%)
  - Manufacturing scalability (20%)
- **Qualitative criteria were also developed to assess the eventual viability of the material candidate for utilization on future missions**
  - Subjective assessment using red/yellow/green color rating
  - Evaluation criteria included: Robustness, Reliability, Manufacturing Repeatability, Development Cost/Schedule Risk, Qualification Cost/Schedule Risk, High-fidelity Thermal Response Model Development & Validation Cost/Schedule Risk, Cost/Schedule Risk for Full-Scale Manufacturing / Life Cycle Costs, Supplier Viability, Extendibility (higher heating conditions), Extendibility (use in deployable applications)

Two Materials Downselected

- **Two materials downselected to carry further and test in more representative conditions**
  - Carbon felt – Phenolic (C-PICA)
  - Carbon felt – Silicone (C-SICA)
- **Next steps**
  - Measure limited thermal and structural properties for each material
    - In-plane and through-the-thickness tensile testing was performed
    - Thermal conductivities were measured with a comparative rod apparatus
  - Test in relevant heatflux and shear
    - Resulted in new test approach

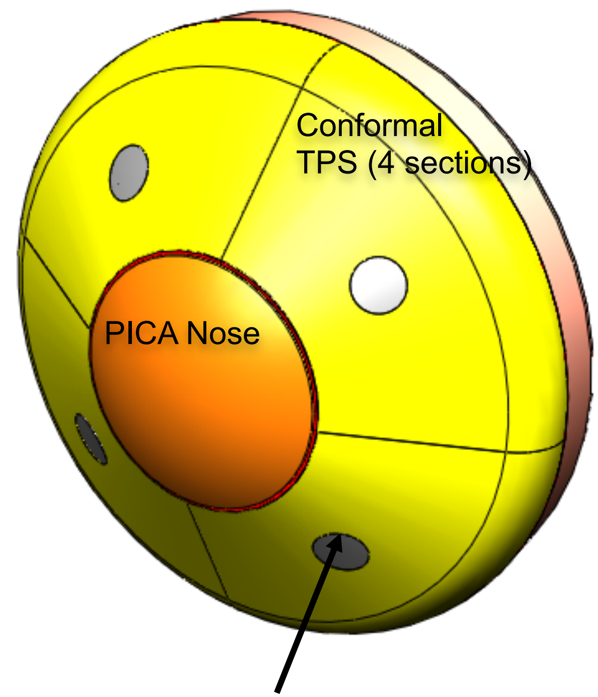
Property Results Summary

- **An initial material property set was obtained to facilitate preliminary thermal and structural response model development**
- **Thermal conductivities of the C-PICA and C-SICA were much lower than PICA, showed low variability, were similar to each other and were dominated by the carbon-felt substrate**
- **C-PICA and C-SICA both exceeded the KPP of 1% in-plane strain at ultimate tensile stress**
- **C-SICA exhibited excellent through-the-thickness strain behavior. C-PICA behavior was similar to PICA, but fiber bridging allows load to be carried after cracks were initiated**
- **Structural properties for both materials had less scatter than PICA properties**

New TPS Shear Testing Approach

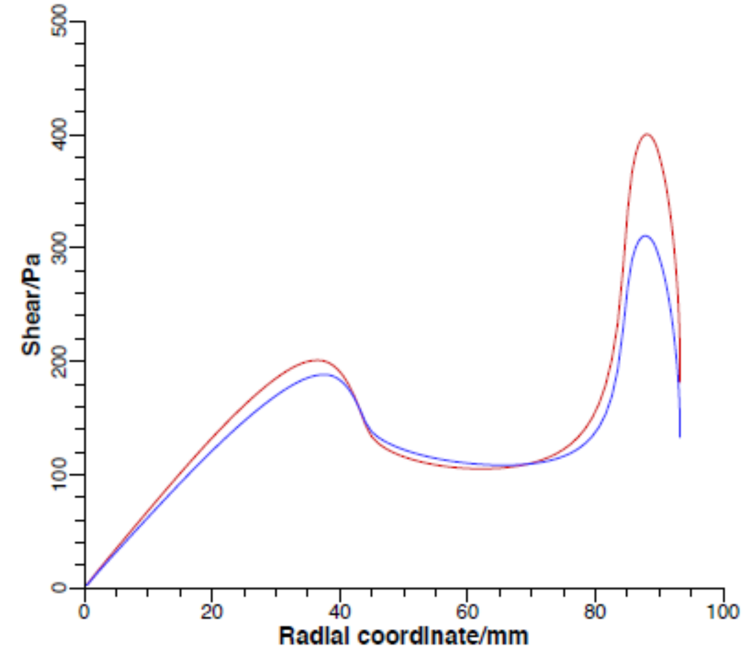
- Heritage shear test configurations (cooled-copper wedges) result in non-representative pressure gradients and often dissimilar flow fields
- New blunt sphere-cone (small probe) design results in flight-like gradients and similar flow fields
- Objectives of the test:
  - Demonstrate moldability of conformable ablators on a curved structure at MSL-type and COTS LEO conditions or beyond (q ~ 250 W/cm^2 or greater)
  - Demonstrate advanced instrumentation of conformable ablators and measure in-situ temperature data for the development of a low fidelity material response model
  - Gather recession and back-face temperature data on conformable ablators in a representative heating, pressure *and* shear environment for verification and validation of materials requirements.

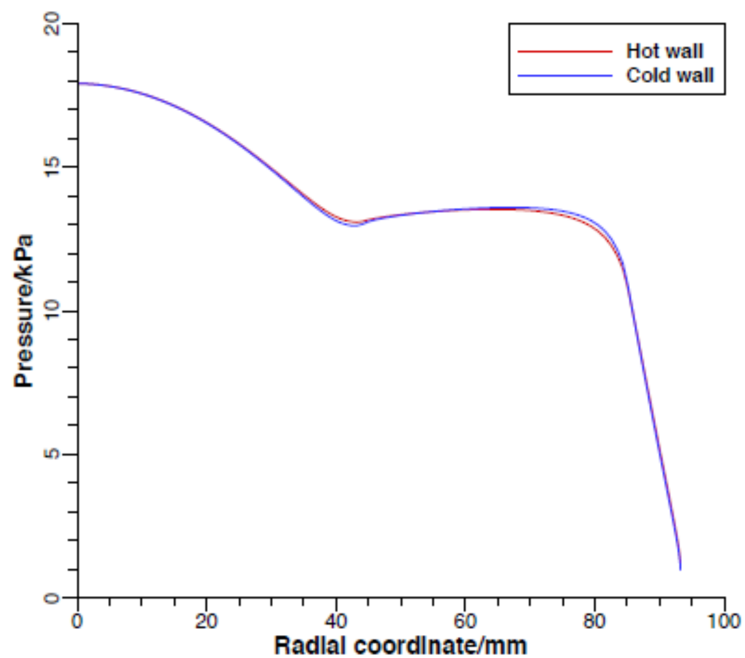
Blunt Sphere-cone configuration

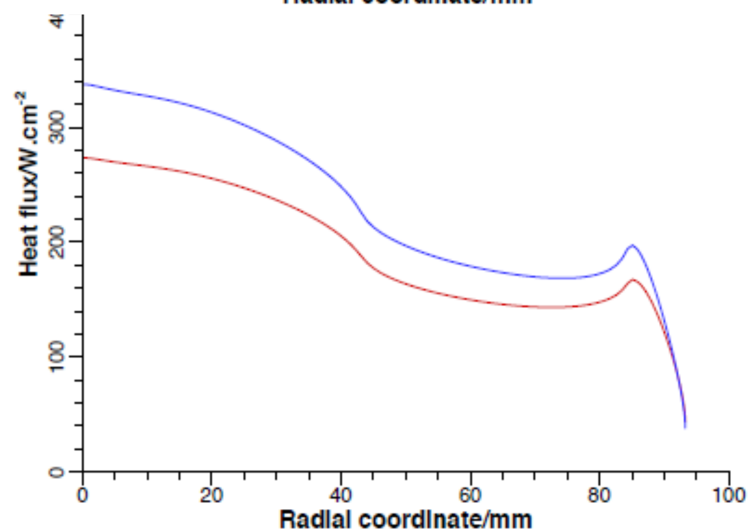


Small Probe (SPRITE 250) Test Details

- Test conditions based on CFD of the **flank** section of a 55°, 7.5” base diameter Small Probe (SPRITE) model
- Example: CFD plots for the 200 W/cm^2 test condition
  - Heat flux decreases slightly
  - Pressure and shear nearly constant on flank

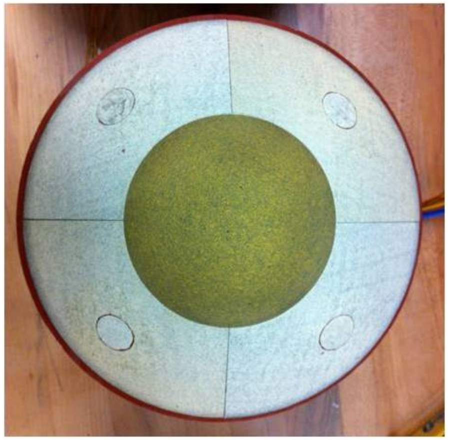






SPRITE Models from Arc Jet Testing in IHF

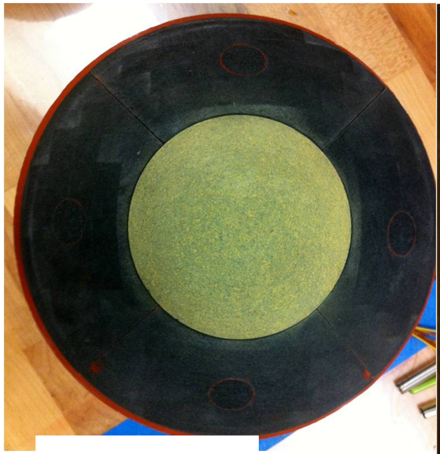
Conformal Ablators



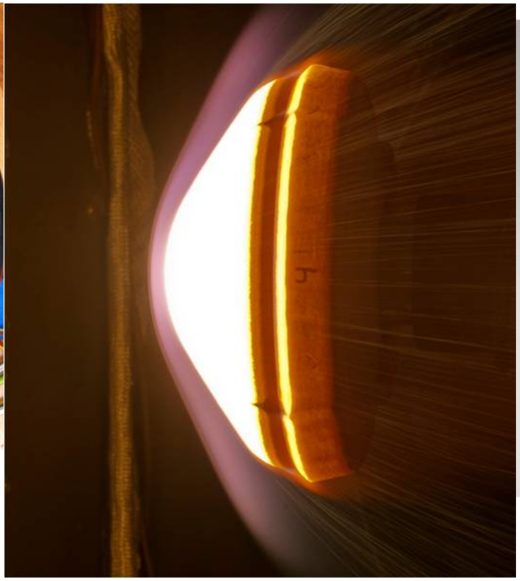
C-PICA

Nosetips lost during retraction of models

Flank heating: ~200 W/cm^2 60 sec | ~400 W/cm^2 30 s



C-SICA



SiO2 (glass) formed on surface

condensed, melted & flowed | vaporized

Results Summary

- **Downselection process used again**
- **Only 1 point difference between C-PICA and C-SICA from Quantitative evaluation**
- **Qualitative evaluation shows *higher risk* for C-SICA in the areas of manufacturing repeatability, materials modeling, and development & qualification cost and schedule**

C-PICA downselected as the most promising material to move forward to the next phase of the technology development

Conformal Ablators

Year 2 Efforts

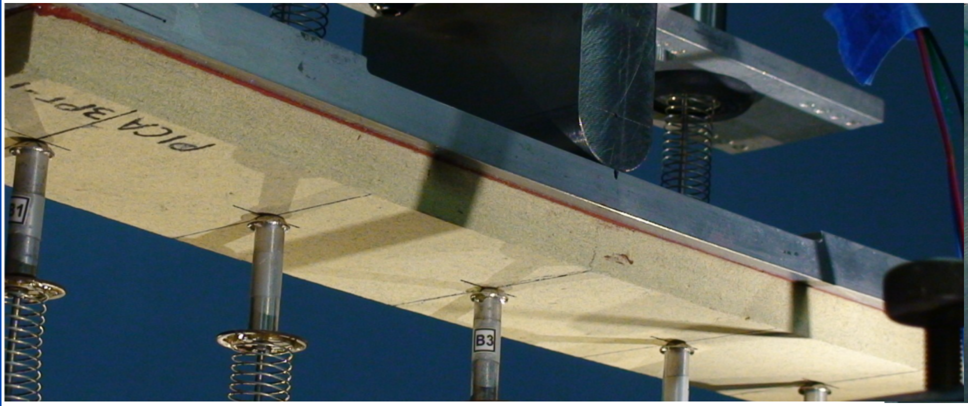
- **Process enough C-PICA for structural properties, thermal properties, materials evaluation and arc jet models**
- **Development of seam techniques**
  - High strain-to-failure allows for larger panels, direct bonding, no gaps between panels
- **Manufacture test articles**
- **Measure structural properties (tensile [IP+TT] and 3- and 4-point flexure)**
- **Measure thermal properties (conductivity, specific heat, TGA)**
- **Modify arc jet specimen design to allow for seam configuration testing**
- **Perform arc jet tests on instrumented segments to provide data for development of a mid-fidelity material response model**
  - Include segment of standard PICA on each test article to get direct comparison of response in each test condition
- **Perform arc jet tests on different seam designs**
- **Demonstrate carbon felt thickness scale up**
- **Develop mid-fidelity material response model**
- **Develop and document final material specifications**

Completed to date

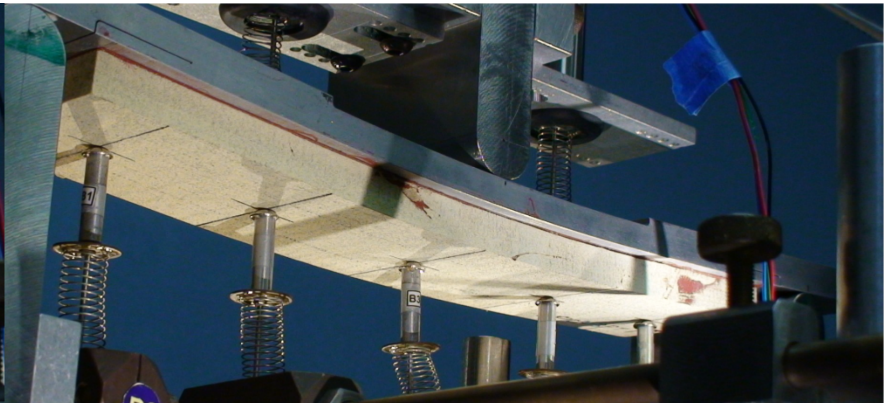
Structural Property Results

- **3-point bend tests**

PICA failure <360 lb, ROC ~135”

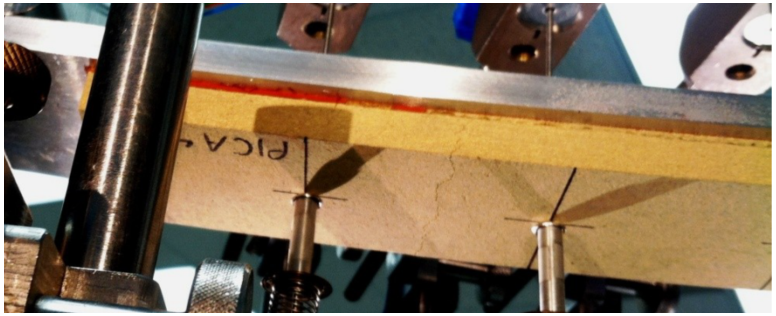


C-PICA failure >1200 lb, ROC ~35”

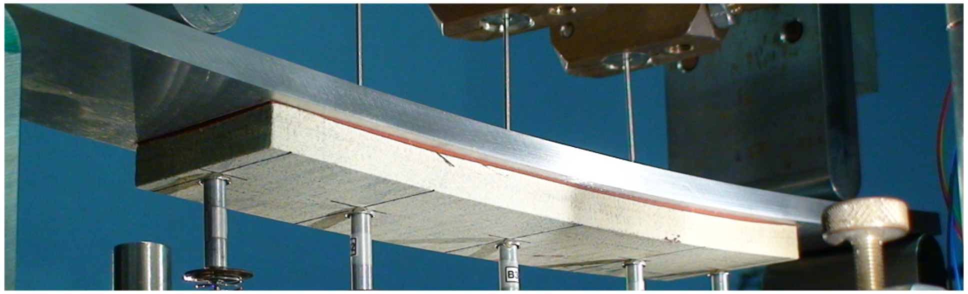


- **4-point bend tests**

PICA failure <750 lb, ROC ~145”



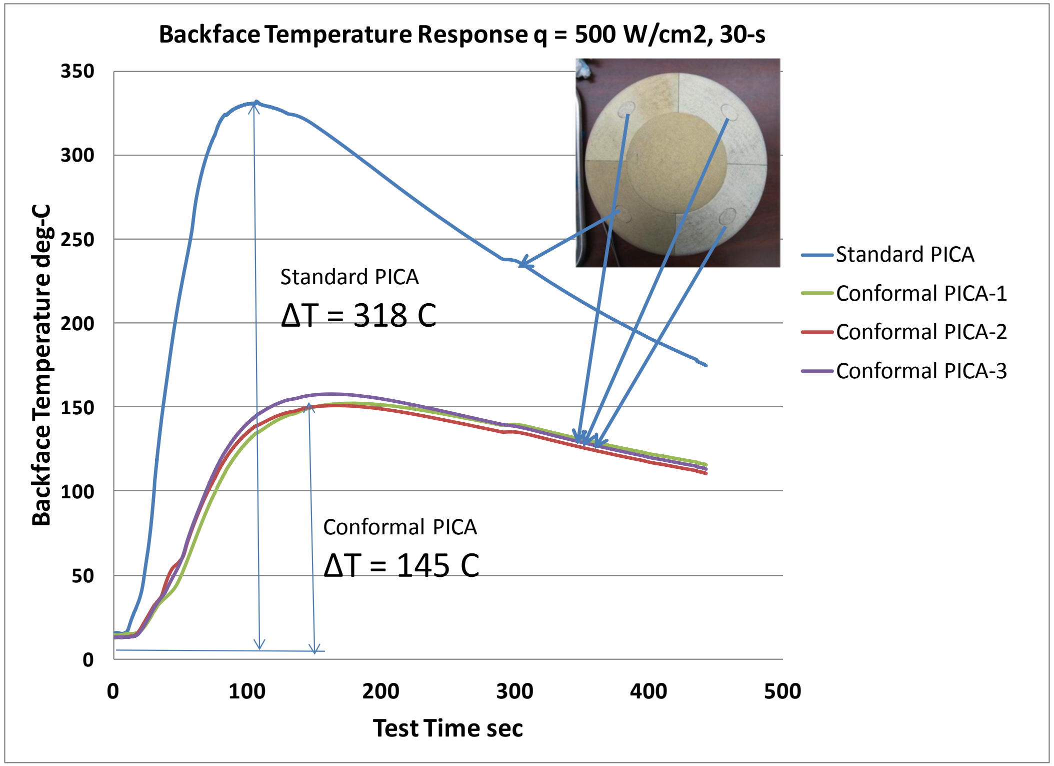
C-PICA no failure at 1500 lb, ROC <65”



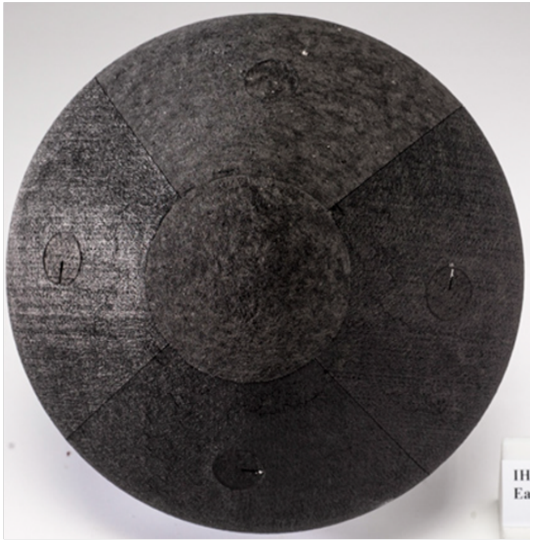
Conformal Ablators

Arc Jet Test Results

- **Improvement over PICA**
  - Recession comparable
  - Thermal penetration much lower

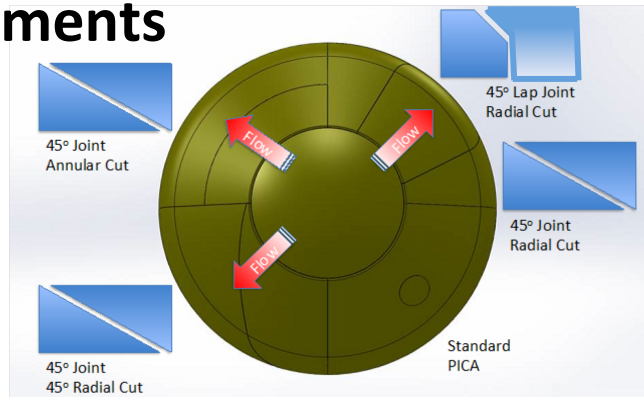


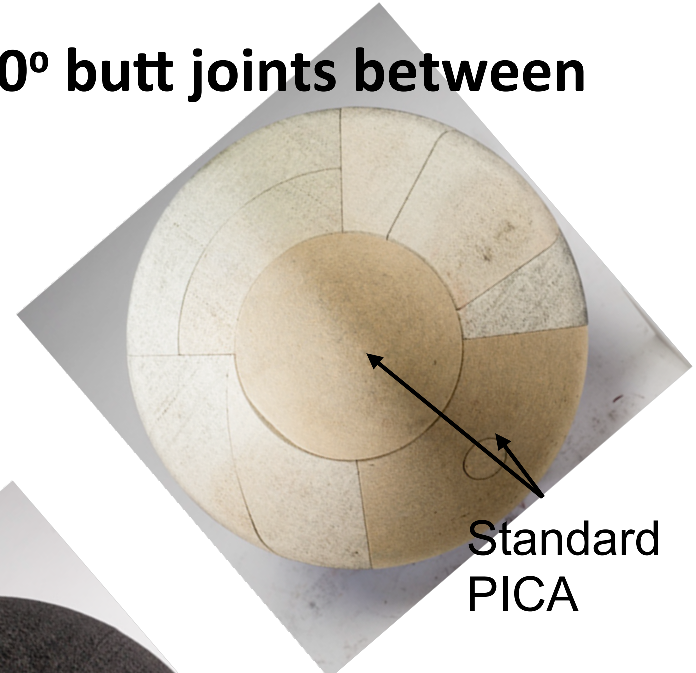
Flank heating ~400 W/cm^2, 30 s



Seam Design Evaluation

- **All seams were well behaved, even 90º butt joints between test segments**

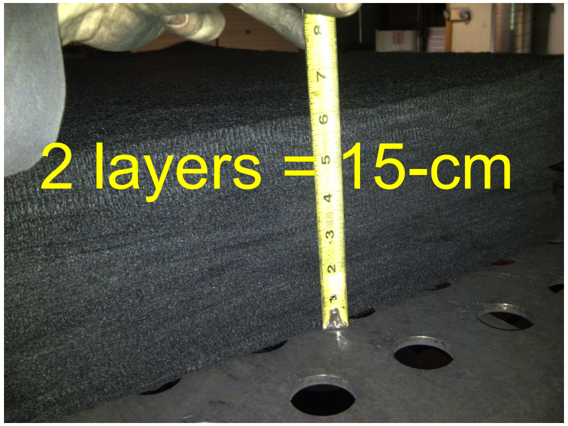


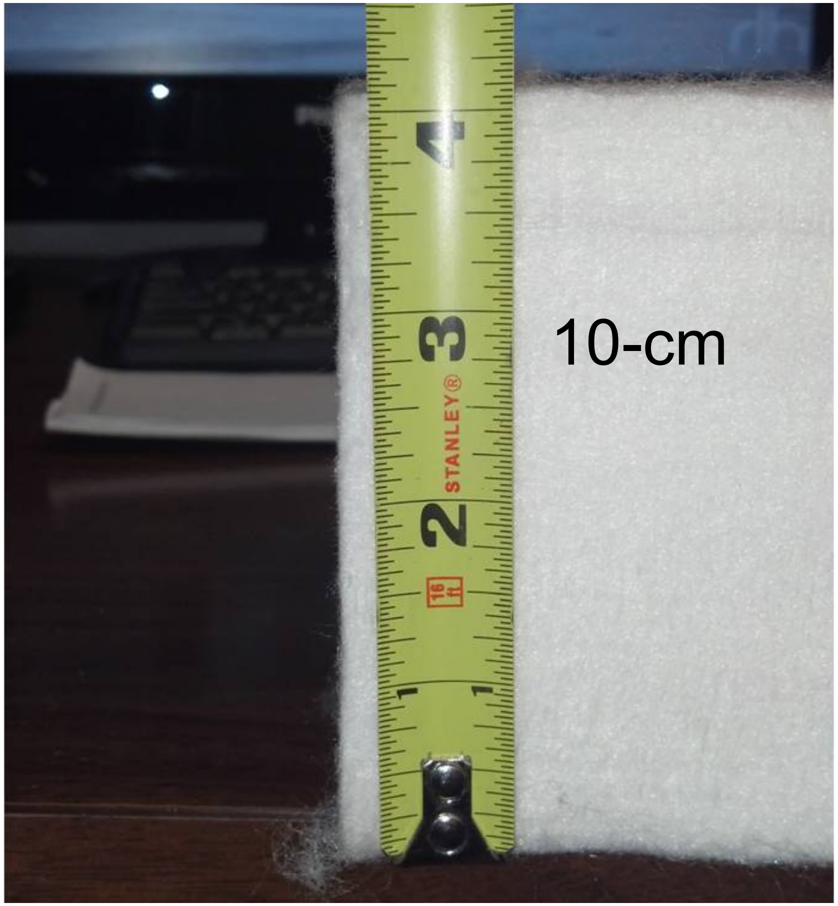


- **Flank heating**
  - ~400 W/cm^2, 30 s

Felt Thickness Scale Up

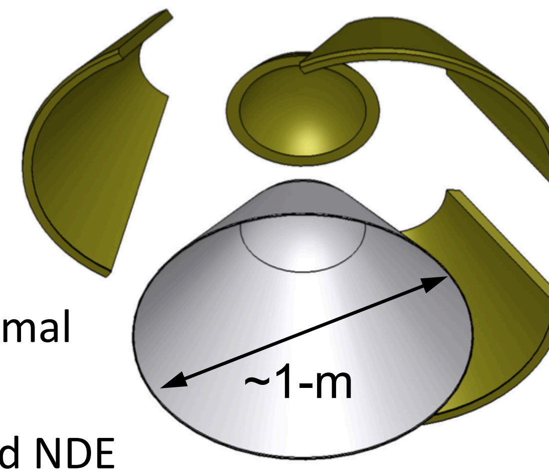
- State of the art for carbon felt ~1.0-in thick, density 0.8-1.0 g/cm^3
- Vendor completed processing of 10-cm thick rayon felt (white goods) at ~525 ounces per square yard (OPSY) – density ~0.23 g/cm^3, material manufactured was 2-m wide by 18-m long
- 16 pieces 2-m wide by 1.5-m long were
- Pilot run results show final thicknesses ~7.5-cm, density ~.127g/cm^3
- 14 pieces carbonized
- 2 pieces retained as white goods
- Impregnation studies underway





Next Steps: Establish Industry Vendor for Scale-up

- Conformal TPS Manufacturing Scale-Up
  - Objectives for 1-m or larger MDU
    - Vendor will be required to supply small-scale samples for materials properties and SPRITE comparison testing followed by large-scale materials for application to the MDU
    - Manufacturing Plan for felt-based conformal ablator materials of at least 1-m diameter: which includes the necessary processes, procedures, equipment, and any services required
    - Non-destructive methodologies necessary to examine variations in the felt structure and the resulting conformal ablator and for bond verification
    - Proposed specifications for certified TPS processing and NDE evaluation of the ablative materials
    - Design support and manufacture of a large manufacturing demonstration unit (MDU)



45° or larger aeroshell

Summary

NASA Ames Research Center has developed a conformal ablator which is:

- **A material that can deliver the same or better performance than PICA but with less weight - every pound saved can be added to more science**
- **A material that is more compliant than the Mars Science Laboratory heatshield material - this makes it more robust to loads and deflections and can save weight as well**
- **A material that, because of it's compliance, can be directly bonded to an aeroshell and installed without gap filler**
- **A material that isn't constrained to current manufacturing dimensions of 50x100 cm… but now should be able to be processed in parts 150x100 cm or even larger, significantly reducing part counts**
- **A material that will require much less "touch labor" than PICA or AVCOAT**

NASA will deliver a TRL 5 material capable of at least 250 W/cm^2 and ready for mission insertion at the end of Year 3 (FY14)